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Math universe: Designing a self-directed learning application for preparing students for mathematical Olympiads

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Abstract: The Mathematics Olympiad serves as a competitive platform for students, characterized by its highly challenging problems. However, a significant issue arises due to the limitations faced by both students and their mentors (teachers) in adequately preparing for such competitions. To facilitate self-directed learning and provide access to a diverse range of practice problems, it is imperative to design an educational application that can be accessed anytime and anywhere. This would maximize time efficiency and enhance students' learning skills in preparation for the Mathematics Olympiad. The proposed application, Math Universe, serves as a medium for students to engage in Self-Directed Learning. Accordingly, the objective of this research is to design Math Universe to effectively and efficiently support students in their preparation for the Mathematics Olympiad. The research employs the Plomp design and development methodology, which includes: 1) Initial investigation phase (situation analysis), 2) Design phase (application design development), 3) Realization phase (application development), and 4) Testing, evaluation, and revision phase (assessment of the developed application's effectiveness). The findings indicate that the design and functionality of the Math Universe application can be optimized to enhance students' effectiveness and efficiency in preparing for the Mathematics Olympiad. Trial results demonstrate that intuitive interface design aspects and easy navigation contribute positively to user experience. Furthermore, the content presented is relevant and comprehensible to students from diverse backgrounds, facilitating interaction and understanding of the material.

Keywords: *Application, Mathematical Olympiads, Quality educations, Self-directed learning.*

1. Introduction

The Mathematics Olympiad is a competitive platform for students [1], where the level of problem difficulty is extremely high [2], requiring exploration skills [3], problem-solving abilities [4], advanced mathematical reasoning, such as algebraic concepts [5], and a deep understanding of the subjects tested in the Olympiad [6]. It is not only students who struggle with solving complex mathematical problems; even university students may encounter difficulties in mathematical problem-solving [7]. The problems presented in the Mathematics Olympiad demand creativity and critical thinking from the participants [8]. However, both students and their mentors (teachers) face limitations in adequately preparing for these competitions. Several studies have highlighted common mistakes made by students when attempting to solve Olympiad-level mathematical problems [9]-[14].

Based on the aforementioned issues, it is essential to provide a platform that supports students' preparation for the Mathematics Olympiad, as mentors or teachers cannot provide guidance at all times, leading to limitations and suboptimal development of students' potential. To facilitate self-directed learning [15] and provide more practical access to a diverse range of problems, it is crucial to design a

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learning application that can be accessed anytime and anywhere. This would maximize time efficiency and enhance students' learning skills beyond what can be achieved in a classroom setting [16].

The application proposed for development in this research is named *Math Universe*. The inclusion of various features within the *Math Universe* application stems from an initial observation of 45 students who are members of the *Komunitas Pecinta Matematika* (Mathematics Enthusiast Community) and participate in mathematics Olympiads. The observation was conducted through a questionnaire that served as a medium for expressing challenges in Olympiad preparation, introducing the application design, suggesting desired features, and selecting learning environments. One of the initial observation results is shown in Figure 1.

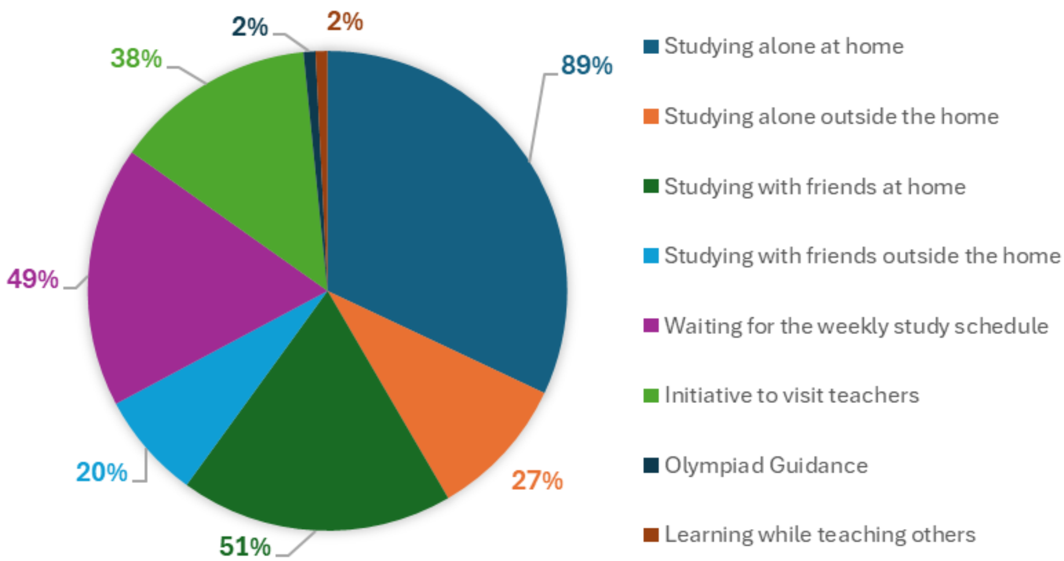

Figure 1.
Student study space options.

Based on Figure 1, 89% of students preferred to study independently at home, while the remainder chose to study outside their homes or wait for weekly schedules. This indicates that students tend to take the initiative in preparing for the Olympiad and find it more comfortable and effective to study in their home environment. Therefore, there is a need for an application that assists them in self-directed learning at home. Independent learning is becoming a necessity for students in the future [17], [18] & [19]. Self-directed learning can be facilitated both offline and online through technology [20], [21], & [22], and the presence of an application can support students' learning [23] and provide easier access to various learning resources through their personal devices. The *Math Universe* application serves as a platform for students to implement Self-Directed Learning.

Self-Directed Learning is essential [24] because it encompasses three core skills: self-monitoring, self-management, and motivation [25]. Through Self-Directed Learning using *Math Universe*, students no longer need to fully rely on mentors for their Olympiad preparation. Based on the description above, the formulation of the research problem in this study is that the development of the design and functionality of *Math Universe* must be optimized to support the effectiveness and efficiency of students in preparing themselves for the Mathematics Olympiad competition.

2. Methodology

2.1. Research Design, Instruments, and Data Analysis

This research employs a qualitative descriptive approach. The use of a qualitative approach can address more complex research questions [26]. Observations, questionnaires, and interviews were utilized to gather supporting data to answer the research questions. Observations were conducted while participants were using *Math Universe*, followed by semi-structured interviews regarding their experiences with the application. These interviews covered aspects such as content, user interface, ease of use, and content relevance. All data were collected with the informed consent and agreement of the various parties involved. The collected data will then be analyzed using descriptive statistics, including mean, standard deviation, and other relevant measures.

2.2. Framework Pengembangan Math Universe

This research utilizes the Flutter framework as the platform for application development, with Visual Studio Code (VSCode) serving as the development environment. Flutter was selected because it uses the Dart programming language, which offers advantages in mobile application development, particularly for Android. Dart is considered to have a simple and easy-to-understand syntax, making the development and maintenance processes more effective and efficient. Moreover, the Flutter framework, combined with Dart programming, allows developers to easily build applications for both web and mobile platforms from a single codebase [27].

Testing and debugging were conducted using the emulator available in Android Studio. The use of this emulator allows for comprehensive application testing without the need for a physical device, enabling the testing process to be carried out flexibly and in a controlled manner. This approach also minimizes the risk of hardware damage during the development phase. Android Studio has been widely adopted to support media development [28].

2.3. Application Development Methods

The Plomp development method was chosen for the development of the *Math Universe* application. The Plomp development model is an approach used to design and develop products, such as applications or learning tools. Additionally, the Plomp model is widely employed in the development of new learning modules [29]. This model is designed to ensure that the developed product meets the needs of users and is effective in its intended context. The phases of *Math Universe*'s application development are illustrated in Figure 2.

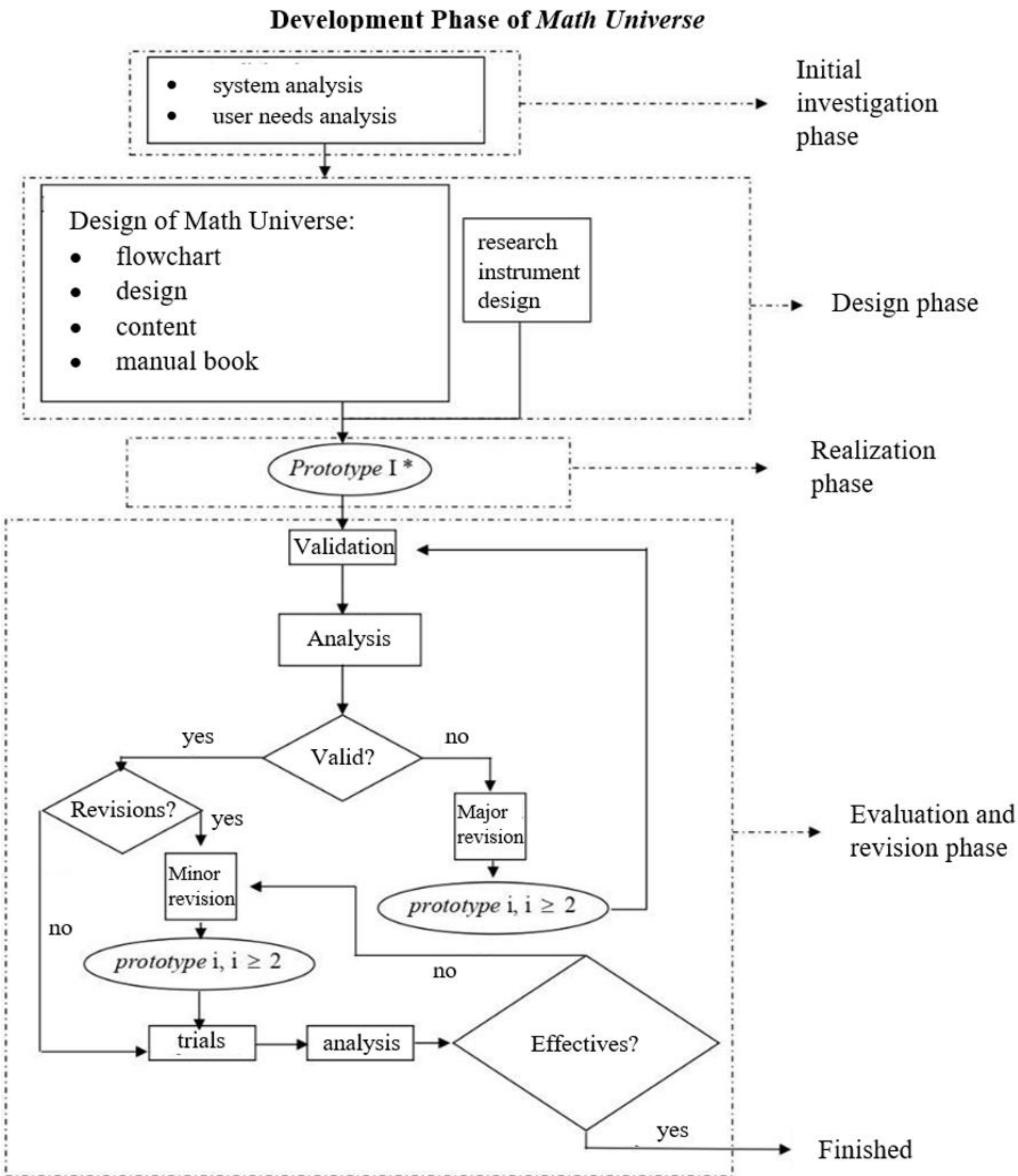

Figure 2.
Math Universe application development flowchart.

2.3.1. Preliminary Investigation Phase

The Initial Investigation Phase was carried out through a needs and context analysis, identifying the problems to be addressed and the users' requirements. The *Math Universe* application will be developed according to the needs of high school students to support their preparation for the Mathematics Olympiad. User requirements were gathered through a series of questionnaires and interviews aimed at collecting information about their specific needs. This phase provides a general

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overview of students' creativity, abilities, experiences, and communication language usage. Additionally, during the initial investigation phase, information from various relevant sources related to the Mathematics Olympiad was also collected [27].

2.4. Design Phase

The design phase is dedicated to planning the structure and framework of *Math Universe*, including the development of the flowchart, storyboard, content, and user guide for *Math Universe*. This phase also involves designing the data collection instruments that will support the research.

2.4.1. Realization Phase

During this phase, *Math Universe* is developed based on the design that was previously established. The version developed at this stage is still a prototype, referred to as *Math Universe*: Prototype I.

2.4.2. Testing, Evaluation, and Revision Phase

In this phase, *Math Universe*, which has been developed, will undergo testing and evaluation. The prototype will be trialed with a limited sample of 40 students, selected through purposive sampling. The selected respondents are high school students who are members of a mathematics enthusiast community in Indonesia. Purposive sampling is chosen to facilitate observation and evaluation during the testing process. The prototype's construct and content validity will be assessed by three experts in their respective fields.

2.5. Validity and Reliability of the Instrument

The validity and reliability of the instrument are based on the validation results from three experts. Each expert will assess the instrument's validity and reliability in terms of both content and language. Feedback from the experts will serve as the basis for refining the instrument. A valid and reliable instrument is essential for effective data collection to address the research questions.

3. Results and Discussion

3.1. Results of the Preliminary Investigation

In the preliminary investigation phase, the primary focus of this study was to analyze the learning methods employed by students in preparing for mathematics olympiads. This stage began with a systematic analysis of the various approaches adopted by students, both individually and in groups, to identify the most effective learning patterns. The analysis covered how students utilized learning resources such as books, tutorial videos, and educational applications available on digital platforms. Furthermore, the investigation explored the extent to which students leveraged information technology to enhance their understanding and mathematical skills.

A qualitative approach, through interviews, was also employed at this stage to gain a deeper insight into students' creativity and problem-solving abilities in mathematics. Interviews were conducted with students who had participated in mathematics olympiads, their mentoring teachers, and educational experts experienced in this field. These interviews provided valuable information on how students developed learning strategies, overcame challenges, and utilized available resources. Additionally, the interviews revealed factors influencing students' motivation and interest in mathematics, as well as how they communicated and shared knowledge with peers and mentors.

The preliminary investigation phase also involved collecting data related to students' learning experiences during their olympiad preparation. This data included students' experiences in accessing learning materials, their interactions with mentors, and how they managed their study time. The analysis also considered the differences in learning approaches between more experienced students and first-time participants, and how these experiences influenced the outcomes achieved. Furthermore, insights were gained regarding the use of communication in the context of mathematics learning, which encompassed students' abilities to understand and explain mathematical concepts both verbally and in writing. Based on the review [30], more experienced students tended to have stronger independent learning abilities compared to new participants. They were more adept at utilizing available resources and managing their study time efficiently. In contrast, new students typically required more guidance from mentors to develop these skills.

The results from this preliminary investigation provide a solid foundation for the next phase of the research, where the focus will shift to the development of more structured learning strategies based on empirical findings. By understanding how students learn and interact with materials and their learning environment, this study aims to contribute significantly to improving the effectiveness of students' preparation for mathematics olympiads. This phase also helps in identifying the strengths and weaknesses of existing methods and provides recommendations for the development of more suitable applications and learning tools that cater to students' needs.

3.2. Results of the Design Phase

3.2.1. Math Universe Design

The design of the *Math Universe* application focuses on creating a simple yet comprehensive user interface that supports independent learning for students, specifically on mathematical olympiad content. Examples of the user interface design can be seen in Figure 3.

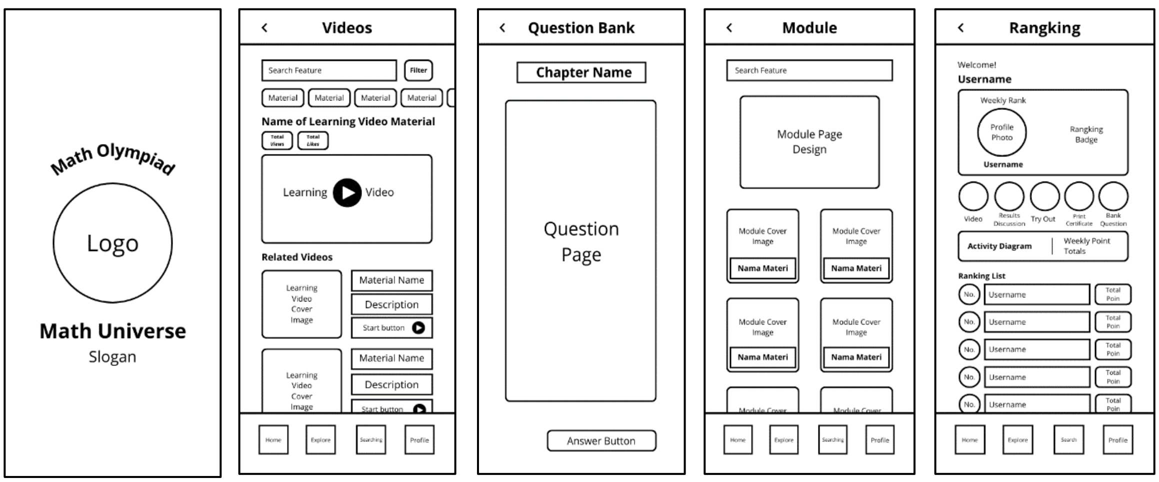

Figure 3.
Some design of user interfaces of *math universe*.

During the design phase of *Math Universe*, a storyboard was first created to illustrate the content displayed on each page. The storyboard for *Math Universe* is shown in Figure 4.

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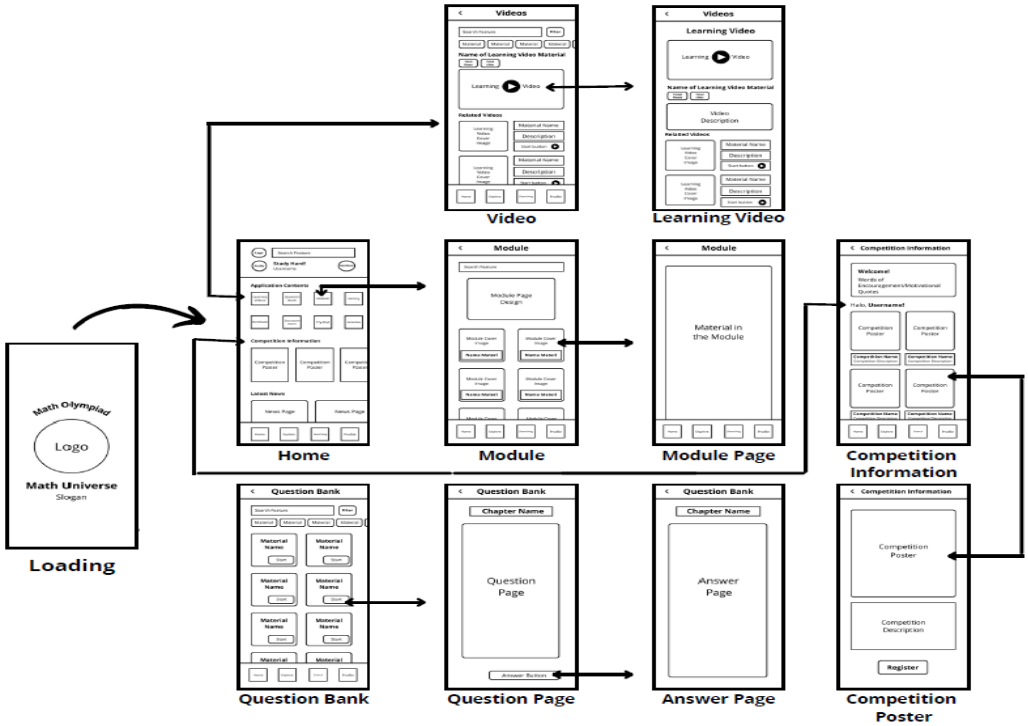

Figure 4.
Storyboard of *math universe.*

In addition to the storyboard, the design also includes the application's data flow structure. This design outlines the relationship between pages and how data moves within the application. Specifically, it illustrates how users navigate from one page to another and how the input data, such as quiz answers or practice results, are processed and stored on a server or within the application's database. Every user interaction, such as clicking buttons or navigating between pages, is designed with careful consideration of user experience and system efficiency [30]. The data flow design and storyboard are two critical elements in the application development cycle that, when combined effectively, can result in a functional and user-friendly application [30]. The Level 1 Data Flow Diagram (DFD) for *Math Universe* is shown in Figure 5.

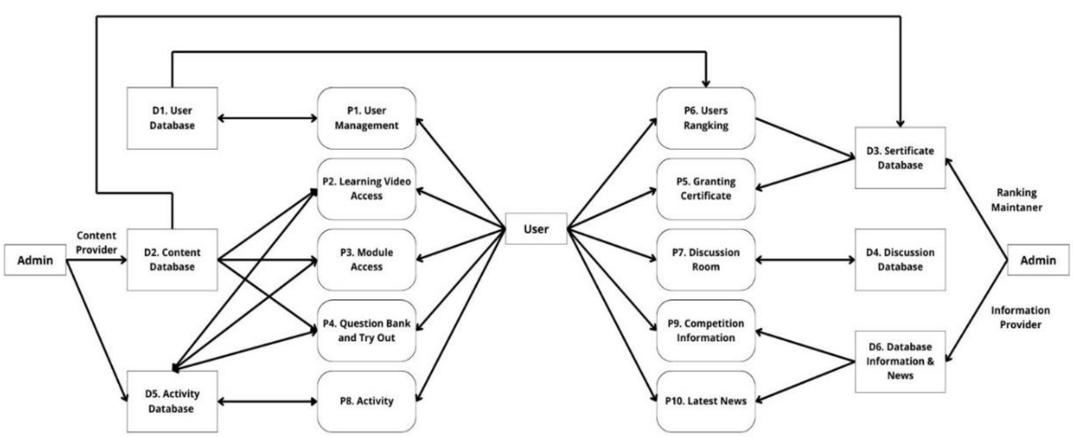

Figure 5.
Data flow diagram level 1 of *math universe.*

3.2.2. Research Instrument Design

The research instruments include semi-structured interviews, questionnaires, and observation sheets, all of which were designed to be validated by experts. Semi-structured interviews allow the researcher to explore respondents' views in depth while adhering to a predetermined question framework. The questionnaire is used to systematically collect quantitative data, while the observation sheet serves to record behaviors or phenomena observed during the research process. These three instruments are validated by experts in the relevant fields to ensure content validity and reliability before being employed in data collection.

3.3. Results of Realisasi Phase

The development of the *Math Universe* application, following the Plomp development model, has resulted in the creation of a self-learning platform designed to help students prepare for mathematics olympiads.

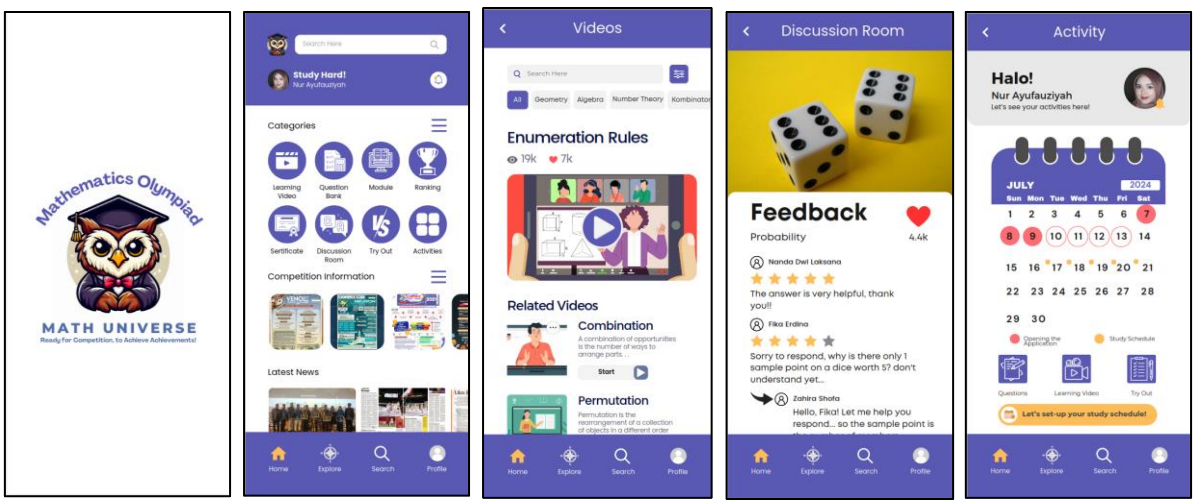

Figure 6.
Some user interfaces of *math universe*.

Math Universe offers various features that enable students to access training materials, specially designed practice questions, videos, and olympiad simulations. The platform is expected to serve as an effective tool for students to enhance their mathematical skills and knowledge independently, while also preparing them for the challenges of national and international mathematics olympiads. To foster collaboration and motivation, *Math Universe* includes a leaderboard that displays student rankings. Students can also participate in daily or weekly challenges, designed to consistently hone their abilities.

With these features, *Math Universe* functions not only as a self-learning platform but also as a community that supports students in achieving their best performance in mathematics competitions. This community aspect allows students to engage not just in individual learning but also to collaborate with their peers in olympiad preparation. It provides opportunities for students to compare problem-solving strategies and gain new perspectives, which are crucial in high-level mathematics competitions. The platform's design, which facilitates community interaction, can lead to increased confidence and academic achievement, especially as students support each other in reaching common goals [30].

3.4. Results of Test, Evaluation, and Revision Phase

The usage statistics of *Math Universe*, based on a trial with 40 selected respondents, are first presented in Table 1. The trial took place over a specific period, from August 1 to August 30, 2024.

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During this time, 40 high school students actively used the application to prepare for the mathematics Olympiad. The data collected includes the frequency of use, the number of questions completed, the time spent on solving problems, the number of modules and videos accessed, and the total video viewing time for each respondent.

Table 1.
Math Universe usage statistics.

Indicators statistics	Means	Std. dev.
Number of questions solved.	24	5.3
Time spent per session (Minutes)	41	10.2
Number of modules opened	3	0.6
Number of videos opened	11	3.1
Length of video watched (Minutes)	6	5.2
Frequency of use of the practice feature	13	4.8
Frequency of use of simulation features	12	3.5
Frequency of use of discussion features	5	2.3

Observations during the trial period indicated that respondents more frequently used the practice feature (an average of 13 times) compared to the simulation feature (an average of 12 times. This suggests that the practice feature was perceived as more engaging or essential for daily preparation by the users. This finding aligns with several studies which suggest that users of educational applications are generally more engaged with features that offer direct practice or repetitive exercises. Features like practice allow users to test their understanding and correct errors, significantly enhancing engagement and learning outcomes [30]. The average session duration was 41 minutes, demonstrating that the application could maintain user attention for a consistent period, supporting findings that consistent usage duration is a key indicator of user engagement.

Secondly, the respondent satisfaction scores regarding the use of *Math Universe* are presented in Table 2.

Table 2.
Math Universe usage satisfaction score.

Indicators satisfaction	Means	Std. dev.
Ease of use	4.2	0.8
Interface design	4.0	0.9
Quality of learning materials	4.5	0.7
Relevance of the question to the Olympiad	4.3	0.6
Application Responsibility	4.1	0.7
Overall satisfaction	4.3	0.8

According to Table 2, several key findings can be identified from the initial trial of the *Math Universe* application. Overall, *Math Universe* received positive feedback, with most respondents appreciating the ease of use, the clean and modern user interface design, and the high quality of the learning materials, which were considered highly relevant and beneficial for mathematics olympiad preparation. However, some users expressed that certain features required too many clicks to access, making navigation somewhat inefficient. Studies show that applications designed with user-friendly and visually appealing interfaces tend to be more preferred by users, as they reduce cognitive load and improve the overall user experience. For example, research [30] indicates that intuitive interface design can enhance user engagement and improve the effectiveness of the learning process.

There were also complaints about the small text size and unclear icons. The average score for ease of use was 4.2, with many users stating that the application was intuitive and easy to navigate. The interface design received an average score of 4.0, with users appreciating the attractive and unobtrusive layout, though some raised concerns about the small text size and unclear icons.

The learning material received an average score of 4.5, with respondents praising the depth and relevance of the content provided, supporting findings from research showing that relevant content can enhance learning effectiveness. The practice questions in the application were also considered aligned with olympiad-level questions, receiving an average score of 4.3. However, some respondents complained that certain questions were too easy and did not challenge them according to olympiad standards. This observation aligns with previous studies that highlight the need for more challenging questions to maximize learning outcomes. Research [31] suggests that offering a variety of difficulty levels in questions is crucial to encouraging critical thinking and problem-solving skills. Questions that are too easy may cause students to lose interest and motivation, as they do not feel sufficiently challenged to further develop their abilities.

The application's speed also received positive feedback, with an average score of 4.1, although some respondents reported slow loading issues. Page loading speed has a significant impact on user experience; research from [32] shows that long loading times can affect users' perceptions of a website. This indicates that mobile app loading speed plays a crucial role in user experience, aligning with several respondents' reports about slow loading times.

Overall satisfaction with the application was rated at 4.3, reflecting a high level of satisfaction among respondents. The next section presents the results of expert validation of the *Math Universe* application. Validation was conducted on content, interface design, language, and relevance. The overall satisfaction score of 4.3 suggests that the application effectively meets user needs, supported by expert validation, which shows that *Math Universe* has met key criteria for educational application development.

Content validation ensures that the materials provided are relevant and aligned with learning objectives, while the interface design evaluation highlights ease of navigation and a positive user experience. The assessment of the language used within the app confirms that the terms selected are appropriate for the target audience, facilitating smoother interaction. Additionally, the relevance of the application in the context of mathematics learning adds further value, making it an effective tool for enhancing students' numerical abilities. With this combination of factors, *Math Universe* not only succeeds in capturing users' attention but also offers an enjoyable and beneficial learning experience.

Table 3.
Expert validation results.

Indicators	Validity	Category
Contents	3.6	Very valid
Design interface	3.3	Valid
Language	3.1	Valid
Relevance	3.4	Valid
Overall validity	3.35	Valid

Finally, the practicality of the *Math Universe* application is assessed. Practicality was evaluated based on content, interface design, language, and relevance. The practicality evaluation encompasses several key aspects, such as the content, user interface design, language, and relevance. The practicality of the content ensures that the materials provided not only align with the curriculum but are also easy for students to comprehend. Meanwhile, the intuitive interface design enables users to navigate the application smoothly, thereby enhancing the overall learning experience [33].

Table 4.
Practically results.

Indicators	Mean	Category
Ease of use	84.3	Practical
Time efficiency	87.1	Very practical
Attractiveness	82.4	Practical
Ease to understanding	79.6	Practical
Benefits	82.5	Practical
Overall	83.18	Practical

According to Table 4, the evaluation of the language used indicates that the terms and explanations provided are understandable to students from diverse backgrounds, facilitating both interaction and comprehension of the material [34]. Furthermore, the relevance of the application in the context of mathematics learning enhances its appeal and effectiveness as a learning tool, making it an ideal choice for students aiming to improve their numeracy skills.

The average practically results 83.18% also indicates that the material provided was effective in helping users grasp the tested concepts. This effectiveness is related to the way the application presents adaptive and interactive content, supported by features that allow users to learn at their own pace and according to their individual needs. Research from international journals also supports the notion that user success rates in learning applications are often linked to the quality of the material and how it is delivered [30].

3. Limitations

Although the *Math Universe* application received positive feedback and demonstrated promising initial results, several limitations must be acknowledged. First, the sample size for the initial trial was relatively small, involving only 40 respondents. This limits the generalizability of the findings and may not fully represent the broader student population. Second, the evaluation relied primarily on self-reported measures, which may introduce bias and subjectivity in the feedback received. Moreover, while the application was designed with a focus on usability, some users reported that certain features required too many clicks, indicating the need for further refinement to improve efficiency and streamline user interactions. Lastly, this study was conducted within a specific educational context, which may limit the applicability of the results to other settings or curricula.

Future research should address these limitations by involving a larger and more diverse participant group, incorporating objective usability measures, and conducting long-term evaluations to assess the application's impact on students' mathematical competencies over time. Additionally, this research focused primarily on the development phase, rather than a comprehensive analysis of broader usage, highlighting the need for further investigation into its potential for wider application.

4. Conclusions

Based on this study, it can be concluded that the design and functionality of the *Math Universe* application can be optimized to support students' effectiveness and efficiency in preparing for the Mathematics Olympiad. The trial results indicate that intuitive interface design and easy navigation contribute to a positive user experience. Additionally, the content presented is relevant and easily understood by students from diverse backgrounds, facilitating interaction and comprehension of the material. However, there are still some areas that require improvement, particularly regarding the efficiency of application usage. Some respondents reported that certain features require too many clicks, which can reduce user convenience. Therefore, it is recommended to further enhance the application's functionality by incorporating user feedback. By optimizing the design and functionality of *Math Universe*, the application is expected not only to serve as an effective tool for improving students' numeracy skills but also to increase their interest and motivation in participating in the Mathematics

Olympiad. Future research is necessary to evaluate the long-term impact of using this application in the context of mathematics competitions.

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